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I also certify that the attached copy of the request for grant of a Patent (Form 1/77) bears an amendment, effected by this office, following a request by the applicant and agreed to by the Comptroller-General.

In accordance with the Patents (Companies Re-registration) Rules 1982, if a company named in this certificate and any accompanying documents has re-registered under the Companies Act 1980 with the same name as that with which it was registered immediately before re-registration save for the substitution as, or inclusion as, the last part of the name of the words "public limited company" or their equivalents in Welsh, references to the name of the company in this certificate and any accompanying documents shall be treated as references to the name with which it is so re-registered.

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Dated 12 SEP 1997

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Your reference 0621/01

Notes
Please type, or write in dark ink using CAPITAL letters. A prescribed fee is payable for a request for grant of a patent. For details, please contact the Patent Office (telephone 071–438 4700).

Rule 16 of the Patents Rules 1990 is the main rule governing the completion and filing of this form.

❷ Do not give trading styles, for example, 'Trading as XYZ company', nationality or former names, for example, 'formerly (known as) ABC Ltd' as these are not required.

Warning
After an application for a Patent has been filed, the Comptroller of the Patent Office will consider whether publication or communication of the invention should be prohibited or restricted under Section 22 of the Patents Act 1977 and will inform the applicant if such prohibition or restriction is necessary. Applicants resident in the United Kingdom are also reminded that under Section 23, applications may not be filed abroad without written permission unless an application has been filed not less than 6 weeks previously in the United Kingdom for a patent for the same invention and either no direction prohibiting publication or communication has been given, or any such direction revoked.

The Patent Office

Request for grant of a Patent

Form 1/77

Patents Act 1977

❶ Title of invention

1 Please give the title of the invention: WAVELENGTH - SWEPT FIBER LASER WITH FREQUENCY SHIFTED FEEDBACK

❷ Applicant's details

❑ **First or only applicant**

2a If you are applying as a corporate body please give:

Corporate name: UNIVERSITY OF SOUTHAMPTON

Country *(and State of incorporation, if appropriate)*: UK

2b If you are applying as an individual or one of a partnership please give in full:

Surname: N/A

Forenames:

2c **In all cases**, please give the following details:

Address: HIGHFIELD
SOUTHAMPTON
HANTS

UK postcode *(if applicable)*: SO17 1BJ

Country: UK

ADP number *(if known)*: 79847002

❹ Reference number

4 Agent's or applicant's reference number *(if applicable)* 0621/01

❺ Claiming an earlier application date

5 Are you claiming that this application be treated as having been filed on the date of filing of an earlier application?

Please mark correct box

Yes ☐ No ☑ ➡ ***go to 6***

please give details below

❑ number of earlier application or patent number

❑ filing date

(day month year)

❑ and the Section of the Patents Act 1977 under which you are claiming:

Please mark correct box

15(4) (Divisional) ☐ 8(3) ☐ 12(6) ☐ 37(4) ☐

❻ Declaration of priority

❻ If you are declaring priority from a PCT Application please enter 'PCT' as the country and enter the country code (for example, GB) as part of the application number.

Please give the date in all number format, for example, 31/05/90 for 31 May 1990.

6 If you are declaring priority from previous application(s), please give:

Country of filing	Priority application number *(if known)*	Filing date *(day, month, year)*
	N/A	

2e and 2f: If there are further applicants please provide details on a separate sheet of paper

Second applicant (If any)

2d If you are applying as a corporate body please give:

Corporate name

N/A

Country *(and State of incorporation, if appropriate)*

2e If you are applying as an individual or one of a partnership please give in full:

Surname

Forenames

2f **In all cases**, please give the following details:

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Country

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❸ Address for service details

❸ *An address for service in the United Kingdom must be supplied*

Please mark correct box

3a Have you appointed an agent to deal with your application?

Yes ☐ No ☑ ➡ *go to 3b*

please give details below

Agent's name GRAHAM JONES AND COMPANY

Agent's address 77 BEACONSFIELD ROAD
BLACKHEATH
LONDON

Postcode SE3 7LG

Agent's ADP number

3b: If you have appointed an agent, all correspondence concerning your application will be sent to the agent's United Kingdom address.

3b If you have not appointed an agent please give a name and address in the United Kingdom to which all correspondence will be sent:

Name ~~MR PETER HUGHES~~

Address ~~OFFICE OF INNOVATION AND RESEARCH SUPPORT~~
~~UNIVERSITY OF SOUTHAMPTON~~
~~HIGHFIELD~~
~~SOUTHAMPTON~~

Postcode ~~SO17 1BJ~~

Daytime telephone number *(if available)* ~~01703/594680~~

ADP number *(if known)* 7028327001

7 The answer must be 'No' if:
- *any applicant is not an inventor*
- *there is an inventor who is not an applicant,* ***or***
- *any applicant is a corporate body.*

7 Inventorship

7 Are you (the applicant or applicants) the sole inventor or the joint inventors?

Please mark correct box

Yes ☐ No ☑ ➡ ***A Statement of Inventorship on Patents Form 7/77 will need to be filed (see Rule 15).***

8 Please supply duplicates of claim(s), abstract, description and drawing(s).

8 Checklist

8a Please fill in the number of sheets for each of the following types of document contained in this application.

Continuation sheets for this Patents Form 1/77			
Claim(s)		Description	4
Abstract		Drawing(s)	3

Please mark correct box(es)

8b Which of the following documents also accompanies the application?

Priority documents *(please state how many)*	0
Translation(s) of Priority documents *(please state how many)*	0
Patents Form 7/77 – Statement of Inventorship and Right to Grant *(please state how many)*	0
Patents Form 9/77 – Preliminary Examination/Search	0
Patents Form 10/77 – Request for Substantive Examination	0

9 You or your appointed agent (see Rule 90 of the Patents Rules 1990) must sign this request.

9 Request

I/We request the grant of a patent on the basis of this application.

Please sign here ➡ Signed Peter Hughes Date 9 *(day)* 9 *(month)* 1996 *(year)*

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Please return the completed form, attachments and duplicates where requested, together with the prescribed fee to either:

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25 Southampton Buildings
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Wavelength-swept fiber laser with frequency shifted feedback

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We report a frequency-shifted, wavelength-swept Er/Yb-doped fiber laser. By matching the intra-cavity filter sweep rate to the frequency shift per round trip controllable, high power (>100mW), cw modeless output over 38nm, with <0.1nm instantaneous linewidth is obtained.

Frequency Swept Fibre Lasers (FSFL's) incorporating Acouso-Optic Tunable Filters (AOTF's) offer great potential for use in a wide variety of applications e.g. spectral device characterization, grating array monitoring and low-coherence optical fibre sensing. However to date FSFL's have received little attention within the literature due to the restricted scanning ranges (<20nm) and ~ 1nm instantaneous linewidths previously achieved [1].

In this paper we demonstrate a diode-pumped, high-power (>100mW), wavelength-swept, FSFL in which the output wavelength is continuously and repeatedly tuned over a broad range (upto 38nm) by modulation of the intracavity AOTF peak-wavelength. Furthermore, we demonstrate for the first time that resonant matching of the filter peak sweep rate to the acousto-optic frequency shift per round trip suppresses the nonlinear pulsing observed in conventional frequency-shift lasers [2,3], and results in significant narrowing of the instantaneous swept linewidth (<0.1nm).

Fig.1 shows the 19m ring laser cavity incorporating a bulk-optic AOTF (4 nm bandwidth, 68 MHz frequency upshift). The acoustic drive to the device was controlled with a phase-locked loop, with fast/independent electrical control of the acoustic power and frequency. Using two phase-locked, arbitrary function generators we could therefore synchronously, and independently temporally control the peak transmission and wavelength of the filter.

We investigated the laser performance under swept operation of the AOTF for a number of sweep ranges, functions and rates. The time averaged laser output was monitored using an OSA and the instantaneous linewidth determined by examining the temporal response of the laser output on reflection from a narrowband (7 GHz) fibre grating. In particular we investigated sweep rates around the resonant case in which the filter peak is moved so as follow the 720

GHz/ms frequency shift imposed by the AOTF. For a 20nm sweep range this corresponds to a sweep rate of ~288 Hz. In Fig.2 we plot measurements of the instantaneous linewidth as a function of sweep rate for the 20nm sweep range case. The results clearly show a strong spectral narrowing at the resonant sweep rate in excellent agreement with our theoretical expectations. Moreover, the laser's natural tendency to pulse [3] was suppressed. On resonance linear radiation moving under the filter peak experiences the lowest system loss making cw operation the preferred mode.

Figs 3a shows the peak-hold spectrum obtained by resonant tracking of the acoustic frequency shift over 20 nm for a fixed acoustic power. The sweep frequency and the output power were 290 Hz and 100 mW, respectively. The spectral shape and output power were almost independent of the sweep rate up to 7 kHz. Sweep ranges >38nm were readily achieved. In Fig 3.b we show that control of the spectral form can be achieved with synchronous frequency and amplitude modulation. Triangular and square wave modulated forms were chosen for this purpose.

In summary, we have reported a wavelength-swept fiber laser with upto 38 nm sweep range, <0.1-nm instantaneous linewidth, user definable spectral shape, and >100-mW output power. We believe such sources to have great potential for use in applications requiring accurate spectral control, or measurements.

References

1. P. F. Wysocki, M. J. F. Digonnet, and B. Y. Kim, Opt. Lett. 15, 879 (1990)

2. W. Streifer and P. Saltz, IEEE J. Quantum Electron. QE-9, 563 (1973)

3. H. Sabert and E. Brinkmeyer, J. Lightwave Technol. 12, 1360 (1994)

Figure Captions

Fig. 1. Experimental wavelength-swept fiber laser with spectral analysis set-up.

Fig 2. Instantaneous linewidth: (a) Filled and Open circles are experimental values at 3 mW and 100 mW output power, respectively. The dotted lines are theoretical fits, assuming the dependence of $(f_{sweep} - f_{proper})^{1/3}$ with f_{proper}=288 Hz [2].

Fig 3. Peak-hold spectrum of the laser output: (a) AO frequency swept from 68 MHz to 69 MHz at fixed RF power giving flat spectral output over 20nm, (b) triangular and square modulated output obtained by synchronous modulation of the filter transmission and peak wavelength.

1/3

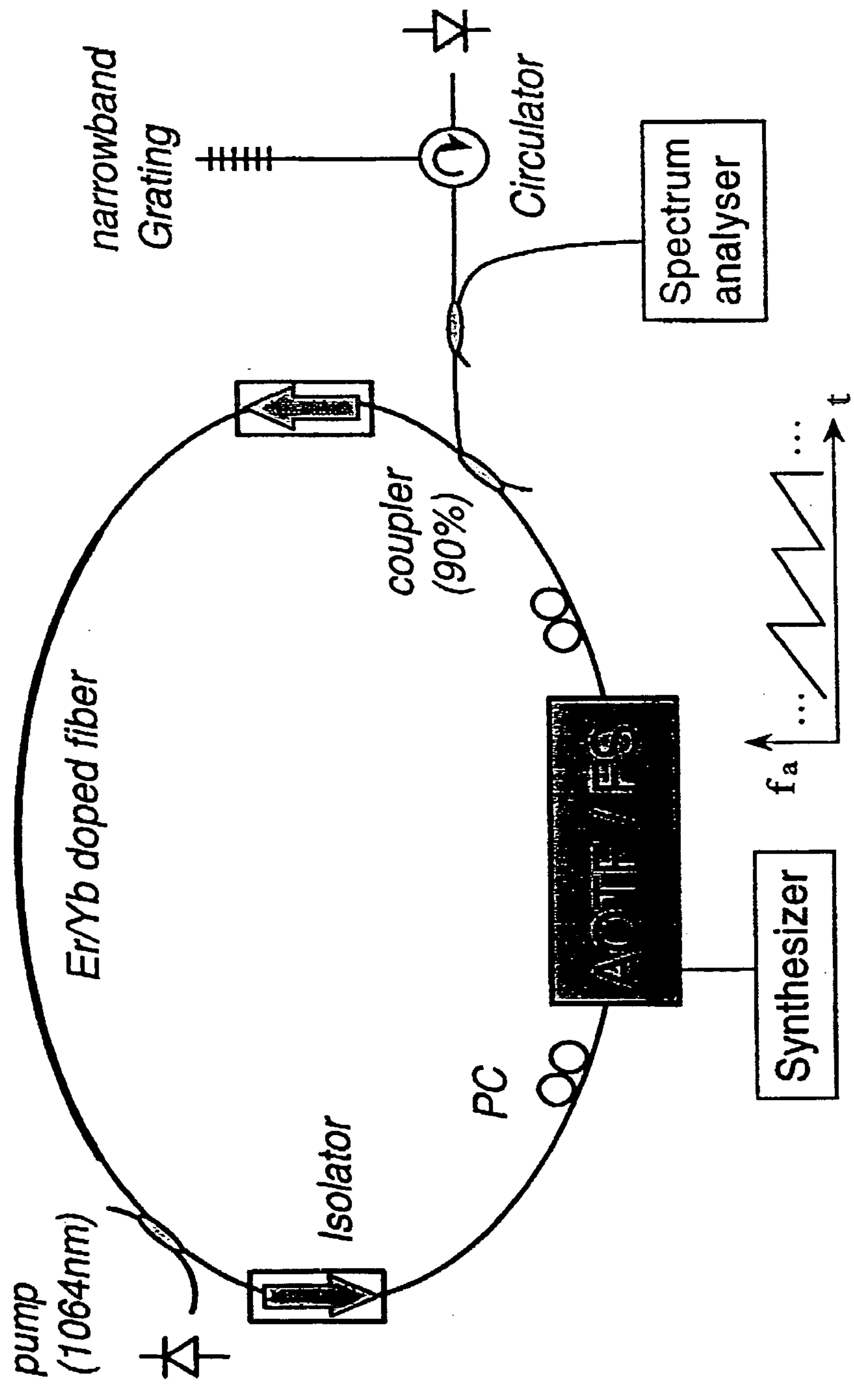
narrowband
Grating
Circulator
Spectrum
analyser
coupler
(90%)
Er/Yb doped fiber
AOTF / FS
Synthesizer
PC
Isolator
pump
(1064nm)
f_a
t

Fig 1

2/3

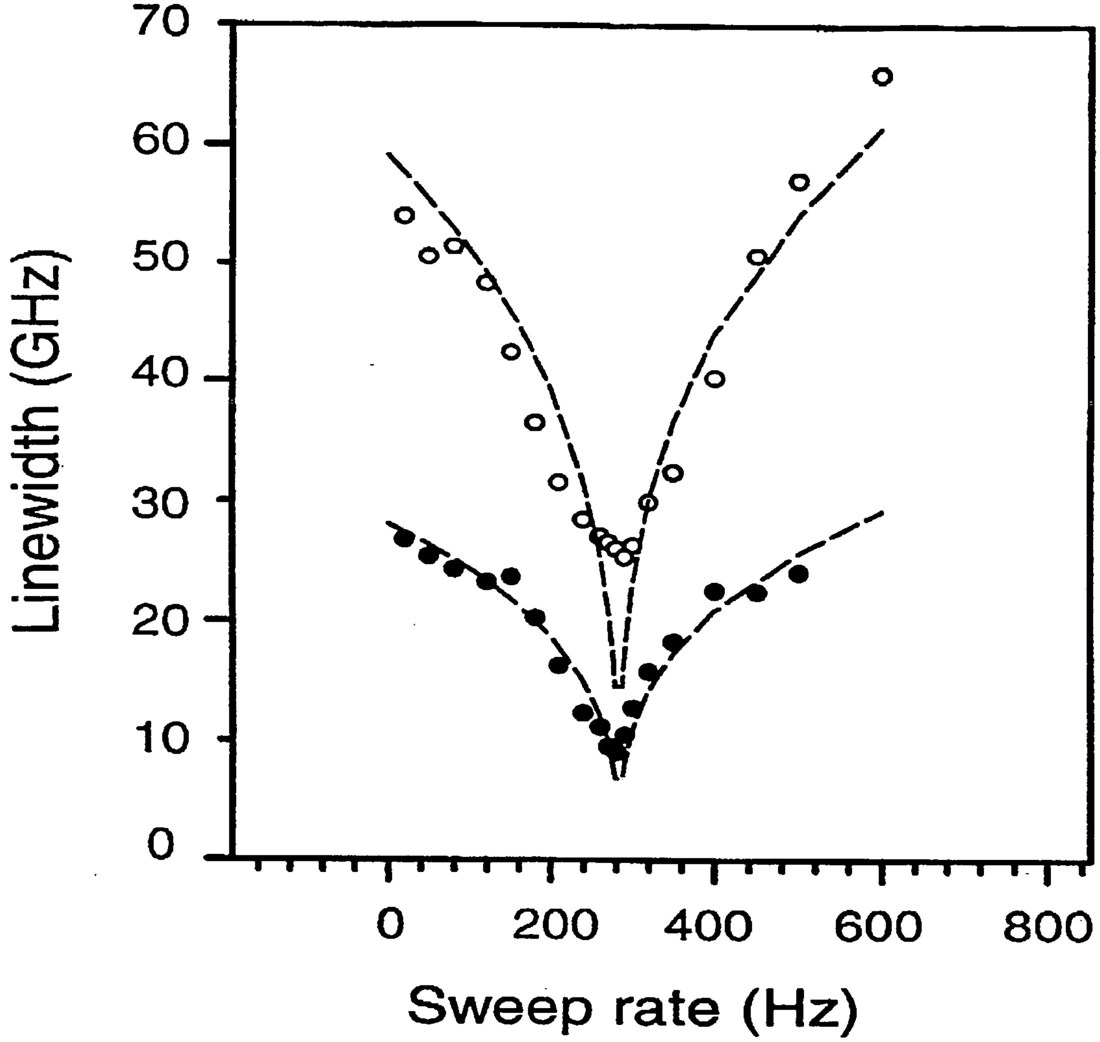
70
60
50
40
30
20
10
0
Linewidth (GHz)
0
200
400
600
800
Sweep rate (Hz)

Fig 2

3/3

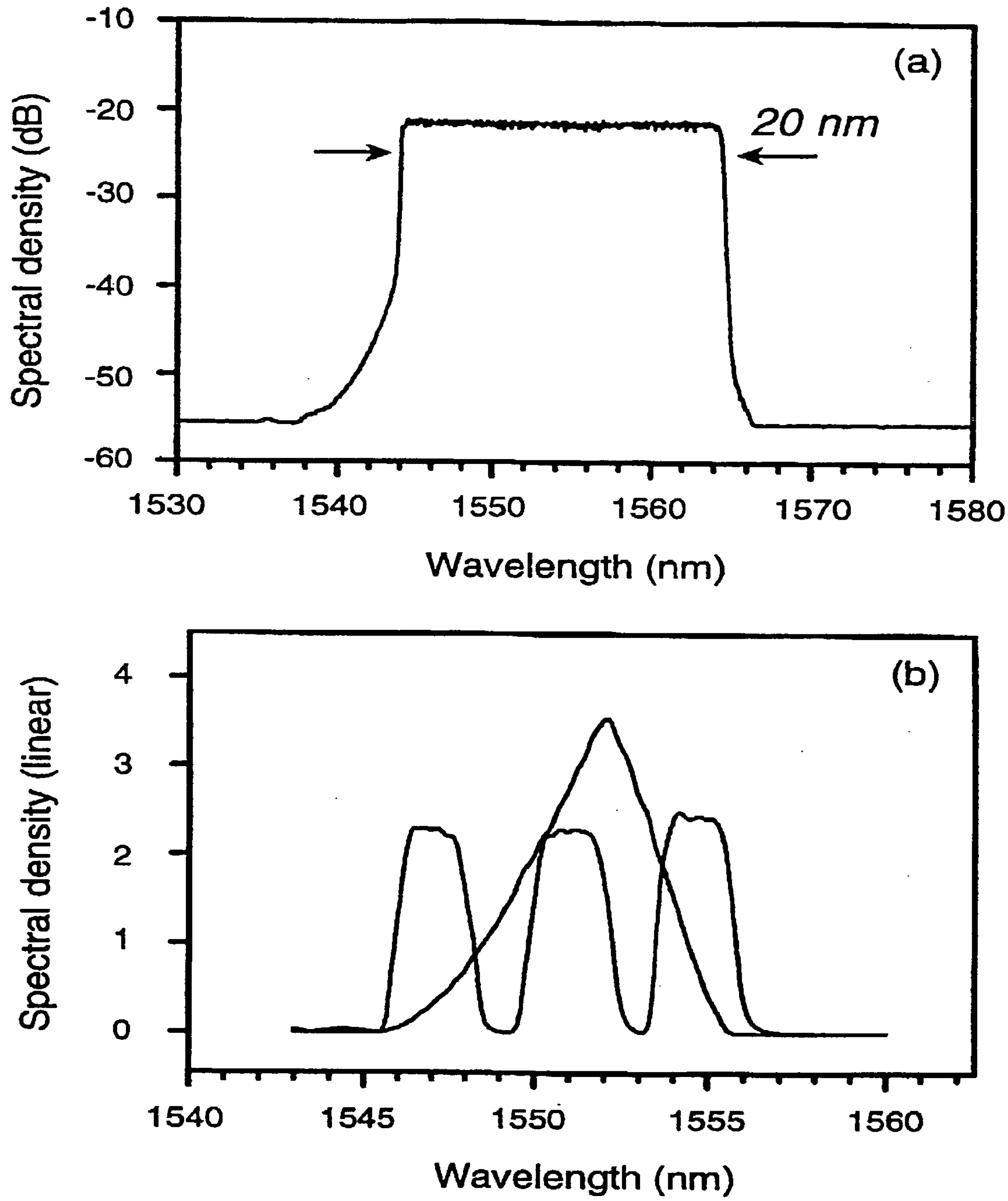
-10
-20
-30
-40
-50
-60
(a)
20 nm
Spectral density (dB)
1530
1540
1550
1560
1570
1580
Wavelength (nm)
4
3
2
1
0
(b)
Spectral density (linear)
1540
1545
1550
1555
1560
Wavelength (nm)

Fig 3